1.0 TECHNOLOGY NAME

LEISA-Based Camera for High Performance, Low Mass, Low Cost, Spectral Imaging

2.0 SPONSORSHIP

2.1 IPDT SPONSOR

D301-286-2042 / 301-286-7701
NASA/GSFC Code 693
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2.2 TEAM MEMBERS

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3.0 OVERVIEW

The Linear Etalon Imaging Spectral Array/Atmospheric Corrector (LEISA/AC or LAC) data reduction and analysis will proceed with the primary objective of demonstrating the feasibility of correction for variable atmospheric extinction. The validity of the correction will be determined by in several ways including: 1) Consistency of ground signal. Regions of the globe will be selected where there is expected to be little variation of the surface characteristics over short time scales, but where there is expected to be atmospheric variability. The multispectral (MS) images will then be variable because of fluctuations in the atmosphere, while the images corrected using the LAC results should show only the much smaller surface variability. If available, ground measurements will be used to determine if the corrected MS images are consistent with the surface properties; and 2) Comparison of water vapor concentrations obtained from LAC with those measured by radiosondes, other satellite sounders, and so on. While this does not necessarily assess the accuracy of the atmospheric correction, it does provide a valuable consistency check. LAC operations will be planned in cooperation with the EO-1 Advanced Land Imager(ALI), Landsat-7 and MODIS observations. LAC will be tested, qualified and calibrated before integration with the spacecraft. It will be delivered in time to go through spacecraft environmental qualification. Full operation must be demonstrated with the spacecraft systems during qualification.

4.0 INTRODUCTION

The ability to accurately correct surface images for atmospheric state will allow full advantage to be taken of the better calibrated and higher signal-to-noise high-spatial resolution surface soundings to be performed by current and future instruments. LEISA/AC is a bolt-on instrument, which can be attached to any future Landsat-type spacecraft (high-spatial, low-spectral resolution multispectral imager).

5.0 TECHNOLOGY DESCRIPTION

We propose to construct a moderate-spatial, high-spectral resolution wedged filter hyperspectral (HS) imager to correct high-spatial, low-spectral resolution multispectral (MS) imagery from EO-1 and potentially other next generation advanced imagers such as ETM+, Advanced Landsat (or LATI), and Resource 21, for the effects of atmospheric variability. This instrument will provide scientific return both in terms of improved imagery and hyperspectral sensing capabilities and will advance a number of technologies that are relevant to new wedged filter multi-head designs for a number of remote sensing applications. The proposed instrument uses a state-of-the-art wedged infrared filter (a linear variable etalon or LVE) placed in very close proximity to a two-dimensional IR detector array to produce a 2-D spatial image which varies in wavelength along one dimension. (The LVE is a wedged dielectric film etalon whose transmission wavelength varies along one dimension.) The filter covers the 0.85 to 1.6 micron spectral region in a distance of 0.9 cm at a spectral resolution of 30 - 40 cm^{-1}, (with a linear dependence of wavenumber on position) and covers a region about 0.76 micron at a resolution of 100 - 200 cm^{-1} in 0.1 cm and represents an advance in dielectric thin film technology. Reflective 1/4-wave stacked layers placed on both sides of one, or more, 1/2-wave etalon cavities provide the spectral resolution. Order-sorting of the etalon is accomplished with lower resolution filter layers. The spectrometer has no moving parts, a minimum of optical elements and only one electronically activated element, the array. Compared to conventional grating, prism, or Fourier transform spectrometers and mechanically or electrically tunable filter systems, it represents a great reduction in optical and mechanical complexity. Furthermore, there are no difficulties associated with taking spectra over multiple wavelength orders, and the positional wavelength dependence and resolution may be tailored to a specific application and may vary over the array.

In operation a two-dimensional spatial image is formed by an external optic, a small, wide field of view (FOV) lens in the case of EO-1, and the spectrum of each point is obtained as the orbital motion of the spacecraft scans the image across the focal plane in wavelength thereby creating a three-dimensional spectral map. The spatial resolution is determined by the spatial resolution of the imaging optic, the image scan speed, and the readout rate of the array. For the EO-1 application, the single pixel spatial resolution is 250 x 250 m^2 (at nadir), corresponding to a readout rate of approximately 33 Hz, and a 360 x 360 $microradian^2$ single pixel field of view at a 700 Km orbit. LEISA/AC will use three identical 256 x 256 pixel IR detector focal plane assemblies in a single box (the optics module). Each array will be placed behind a lens with a five degree FOV to obtain a swath width of 185 km (~15 degrees). The optics module will be bolted to the spacecraft and bore-sighted with the large telescope used by the high-spatial resolution imager. The electronics necessary to interface with spacecraft C&DH will be contained in a separate box (the electronics module) at a convenient distance from the focal plane assembly. Because the long-wavelength cut-off is 1.6 micron, the detector plane may be operated at ambient temperature (~300 K), however, to increase the signal-to-noise ratio, LEISA/AC will employ a thermoelectric cooler to stabilize the temperature at 285 K. Solar, lunar, and ground targets will be used in-flight for calibration and flat fielding.

LEISA/AC is intended to correct for water vapor variations, to detect cirrus clouds (through the 1.38 micron channel), and to provide such aerosol information as can be determined from the 0.85 to 1.6 micron region and the 0.76 micron O_2 band absorption measurements. The 0.45 micron MS data itself will be used to determine the effect of smaller aerosol particles. If this flight indicates that it is advantageous to include these spectral regions and other dark vegetative spectral regions then future atmospheric correctors will do so. The spatial resolution of 250 meter was chosen to optimize the sampling since neither water vapor nor aerosols are expected to vary greatly on this scale, while the pixel size should insure that there are numerous cloud-free pixels in most scenes. Smaller IFOVs would increase the data rate and required storage quadratically. Larger IFOVs would decrease the number of cloud-free spectra at a faster than linear rate, and the spatial variations of the retrieved water vapor and aerosol burdens would become increasingly non-representative of the true gradients. Sampling the spectrum linearly in wavenumber is appropriate to gas-phase atmospheric spectra, and it tends to decrease the dynamic range required to match the solar flux, relative to constant or constant resolving power (/).

Several approaches to the correction problem shall be investigated: 1) solving for water vapor, aerosol, and surface reflectance in a fully coupled radiative transfer model assuming forms for the wavelength dependence of the aerosol extinction and surface reflectance, and using a parameterized model of water vapor transmittance functions, 2) solving the system sequentially, first for water vapor using ratios of on- and off- line transmittances, assuming negligible wavelength variation of surface reflectivity and aerosol extinction over small wavelength excursions, and then for aerosols and surface reflectance using the retrieved water vapor and 3) using a regression type analysis to predict the atmospheric effects on the Landsat-type multi-spectral channels based on either observational or model statistics. In the first two cases, the retrieved atmospheric parameters would be used to model the atmospheric effect on the Landsat-type multi-spectral channels from parameterized transmission models. Note that since the observed fluxes are due to transmitted and reflected solar radiation, the atmospheric transmittances will only have a weak temperature dependence. For those regions which are partially cloudy in the LEISA/AC data, but which contain clear pixels in the higher spatial resolution multi-spectral data, the effects of interpolation schemes shall be tested in the correction algorithm.

In addition to providing a basis for performing a good atmospheric correction, LEISA/AC data will be of scientific interest and commercial utility in its own right because of its continuous spectral coverage at moderately high spectral resolution. For example, the data may be used to obtain: 1) cloud information including particle size, phase and cloud height and areal extent for climate studies and precipitation forecasts; 2) aerosol composition and particle size, including volcanic aerosols which are of interest to airlines for flight path planning; 3) vegetation liquid water content; and 4) cloud, ice, and snow discrimination and extent and age of snow fields, which is useful for spring water runoff prediction. In general, the higher spectral resolution gives LEISA/AC the capability to do much better spectral discrimination than the multi-spectral data, albeit at reduced spatial resolution. There is thus the likelihood that the data sets may be combined in a synergistic fashion to provide much more information than would be possible from either data set in isolation.

6.0 TECHNICAL VALIDATION OBJECTIVES

6.1 TECHNICAL VALIDATION OBJECTIVE #1

The first technical validation objective will be to determine that the three arrays are operating, and to determine what changes, if any, have occurred in the spectral and radiometric calibration since pre-launch testing.

6.1.1 Required Data/Necessary Measurements:

The temperatures and voltages of the focal plane will be required along with a few LAC ground scenes, a solar and a lunar calibration scan. Dark frames (either deep sky or unlit earth) and blackened rows on the arrays will be used to estimate dark current.

6.1.2 Approach:

The dark currents, uniformity and response of the filter/array assemblies shall be compared to similar measurements made during the pre-launch calibration phase. Assuming the detectors are working, the measured atmospheric spectrum will be used to obtain the wavelength calibration. The solar and lunar scans will be used to determine the intensity calibration.

6.1.3 Anticipated Results:

We expect that the calibrations will not have changed since I&T, however, if there are changes, we will be able to determine their magnitude by comparison with the pre-launch measurements and will use the new numbers for future calibration. Periodic calibration in-flight will insure that the absolute radiances maintain their accuracy

6.1.4 Supporting I&T Data:

The pre-launch wavelength calibration shall be obtained using a variety of tunable (grating monochrometers) and fixed (calibration lamps) spectral sources. The pre-launch radiometric calibration shall be established using calibrated black bodies. The uniformity shall be determined from incandescent lamp and black-body flat fields.

6.1.5 Rationale:

Comparison of pre- and post-launch calibrations will determine the change in system performance as a function of time. The various measurements should be sufficient to determine which components are changing (i.e. the lens, the array or the filter), or if a system change is occurring (e.g. the TE cooler is less efficient). The effects of these changes will be included in the calibration algorithm.

6.2 TECHNICAL VALIDATION OBJECTIVE #2:

The second technical validation objective will be to determine the trajectory of the field of view during a data event, and to use that information to resample the LEISA/AC wedge imager data, if necessary, to provide a high-fidelity data cube.

6.2.1 Required Data/Necessary Measurements:

A sequence of ground scenes obtained by LAC, the ALI, the Wedged Imaging Spectrometer (WIS), the Grating Imaging Spectrometer (GIS) and the associated spacecraft attitude data. The LEISA/AC data sequence should consist of at least 256 images.

6.2.2 Approach:

Successive images shall be used to calculate cross correlations among the LAC data. Assuming relatively smooth motion, the track that maximizes the cross correlation throughout the data event shall be determined. Since there are essentially identical spectral segments at the beginning and end of a given image, image segments taken from the first few rows of a scan will be at the same wavelengths as image segments taken from the last few rows about 8 seconds (60 km) later.

6.2.3 Anticipated Results:

We expect that the spacecraft track of the LAC will be determinable to the sub pixel level.

6.2.4 Supporting I&T Data:

The relative orientation of the LEISA/AC with the spacecraft axis, as determined from the image track and the spacecraft attitude data, shall be compared to the pre-launch condition. The pre-launch imaging tests will be used to correct for the minor effects of image distortion, if necessary. The pre-launch MTFs shall be used.

6.2.5 Rationale:

The image path determined by cross-correlation measurements using LEISA/AC will be compared to the spacecraft attitude data and the track determined from the higher spatial resolution, ALI, WIS and GIS imager data. Since the uncertainties and drifts in spacecraft pointing and tracking during a data event will be relatively small and smooth, the cross-correlation technique will determine the track to the sub-pixel level. This will allow the LAC data to be correctly sampled. For those cases where it can be determined that the image track was directly along a column, LAC can be analyzed at its full spatial resolution.

6.3 TECHNICAL VALIDATION OBJECTIVE #3

The third technical validation objective will be to determine the relative pointing of the ALI and the LAC.

6.3.1 Required Data/Necessary Measurements:

A sequence of ground scenes obtained by LAC and the ALI and the associated spacecraft attitude data. The spectral shape of the ALI channels shall also be required.

6.3.2 Approach:

Successive images shall be used to calculate cross correlations between the appropriately spectrally averaged LAC images and the appropriately spatially averaged ALI images. The relative displacement between the ALI images and the LAC images giving the highest correlation will be taken as giving the relative pointing difference between the two instruments.

6.3.3 Anticipated Results:

We expect that the relative pointing will be determinable to much better than the LAC pixel size.

6.3.4 Supporting I&T Data:

The relative orientation of the LAC and the ALI shall be compared to the pre-launch condition.

6.3.5 Rationale:

Knowledge of the relative boresights of the ALI and the LAC will allow the LAC data to be correctly used to correct the ALI for the effects of variable atmospheric extinction.

7.0 SCIENTIFIC VALIDATION OBJECTIVES

7.1 SCIENTIFIC VALIDATION OBJECTIVE #1:

The first scientific validation objective will be to use the LAC data (under cloud-free conditions) to correct the ALI data for the effects of atmospheric extinction.

7.1.1 Required Data/Necessary Measurements:

The temperatures and voltages of the focal plane will be required along with a series of LAC scenes and the associated ALI scenes. The ALI data should be taken over regions where the surface properties are expected to be stable over a period of time sufficient to allow a relatively extended set of comparisons to be made. Solar and lunar scans will also be used for intensity calibration. Initially, cloud-free data, as determined from the ALI measurements and/or local weather data, will be used. The estimated ground location of the data is required. LAC dark frames and blackened rows on the arrays will be used to estimate dark current. Ground and/or aircraft measurements of the surface characteristics will be used if they are available. The ALI channel spectral characteristics will also be required

7.1.2 Approach:

Several approaches to the correction problem shall be investigated: 1) solving for water vapor, aerosol, and surface reflectance as a fully coupled radiative transfer model assuming forms for the wavelength dependence of the aerosol extinction and surface reflectance, and using a parameterized model of water vapor transmittance functions, 2) solving the system sequentially, first for water vapor using ratios of on- and off- line transmittances, assuming negligible wavelength variation of surface reflectivity and aerosol extinction over small wavelength intervals, and then for aerosols and surface reflectance using the retrieved water vapor to calculate transmittances in the regions between the water vapor lines, and 3) using a regression type analysis to predict the atmospheric effects on the Landsat-type multi-spectral channels based on either observational or model statistics. For the first two approaches outlined above, the retrieved atmospheric parameters would be used to model the atmospheric effect on the Landsat-type multi-spectral channels from parameterized transmission models. These approaches will also require the development of a full retrieval algorithm. This development will take place before launch using simulated data, and will be refined after launch for the real system.

7.1.3 Anticipated Results:

We expect that the atmospheric correction will remove a large portion of the effect of variable atmospheric extinction from the ALI data. This would show up either as reduced variability of the images for stable areas, or as improved agreement between ALI reflectances and ground-truth surface measurements. The spatial correlation of the image fields should also increase for regions where there is only a small variability of the surface over a large region. Successful atmospheric correction will improve the utility of the MS images.

7.1.4 Supporting I&T Data:

All the pre-launch image quality, MTFs, wavelength and intensity calibration data and relative pointing data shall be used, although some of these (the calibration and relative pointing) shall also be determined in-flight.

7.1.5 Rationale:

If the atmospheric correction algorithm does remove a significant amount of the atmospheric contamination of the surface data, then the corrected MS images should be more indicative of the surface reflectance properties. In those areas where the surface properties are stable, this will show up as a reduced variability of the ALI images over the time of successive image collections. Where independent (ground or aircraft) measurements of the characteristics of the surface are available, the measured (or modeled) solar reflectance should show greater agreement with the corrected ALI data than with the uncorrected data. For large regions where the inherent surface variability is small, the removal of the atmospheric variability will increase the spatial correlation in the image.

7.2 SCIENTIFIC VALIDATION OBJECTIVE #2

The second scientific validation objective will be to use the LAC data (under partially cloudy conditions) to correct the ALI data for the effects of atmospheric extinction.

7.2.1 Required Data/Necessary Measurements

The same 7.1.1, except that partially cloudy regions will be included as well.

7.2.2 Approach:

Initially, two approaches shall be used to correct for the presence of clouds: 1) Use only those pixels determined to be cloud free to interpolate the correction to cloudy LAC pixels using smooth functions and 2) Estimate the cloud free radiance in LAC pixels with fractional cloud covers determined from the LAC spectrum. Only cloud free ALI pixels will have the atmospheric correction applied to them. Correction of ALI data to provide estimated cloud-free radiances is beyond the scope of the LAC atmospheric correction effort. If cloud-corrected ALI are supplied, then we will provide the atmospheric correction using LAC data.

7.2.3 Anticipated Results:

If the cloud correction is successful, then the results would be as in 7.1.3.

7.2.4 Supporting I&T Data:

The same as 7.1.4.

7.2.5 Rationale:

If the cloud correction is successful, then the rationale given in 7.1.5 will apply.

7.3 SCIENTIFIC VALIDATION OBJECTIVE #3

The third scientific validation objective will be to use the LAC data to retrieve atmospheric parameters such as water vapor, aerosols and clouds, and to use the hyperspectral character of the LAC to infer additional surface properties (plant liquid water content, cloud/snow differentiation and snow field extent, etc.) at the resolution scale of this instrument.

7.3.1 Required Data/Necessary Measurements:

The temperatures and voltages of the focal plane will be required along with a series of LAC scenes. Solar and lunar scans will also be used for intensity calibration. The estimated ground location of the data is required. LAC dark frames and blackened rows on the arrays will be used to estimate dark current. For validation of the products, independent measures of the atmospheric constituent burdens from sources such as satellite sounders, aircraft measurements and radiosondes will be required. Retrieved surface and cloud properties will also require the appropriate verification data.

7.3.2 Approach:

The atmospheric constituents shall be retrieved using the first two approaches outlined in 7.1.2. Assuming that the atmospheric retrievals are verified, then the algorithms for additional atmospheric and surface properties will be developed as the mission progresses.

7.3.3 Anticipated Results:

The retrieved atmospheric and surface parameters should be consistent with independent measures. In those locations where specific verification is not available, the spatial correlation of the retrieved parameters shall be verified against expected patterns.

7.3.4 Supporting I&T Data:

The same as 7.1.4.

7.3.5 Rationale:

The successful retrieval of atmospheric and surface properties over the entire 185 km swath of the LAC will provide valuable products in addition to the atmospheric correction function. The verification of the products will also provide an indirect validation of the atmospheric correction.

7.4 SCIENTIFIC VALIDATION OBJECTIVE #4

The fourth scientific validation objective will be to use the LAC data to correct Landsat-7 data for the effects of atmospheric extinction.

7.4.1 Required Data/Necessary Measurements:

The same data will be required as for objectives two and three except that in addition Landsat-7 data nearly coincident in time will be required, along with its calibration and filter functions.

7.4.2 Approach:

The Landsat data shall be corrected in the same manner as the ALI data.

7.4.3 Anticipated Results:

It is expected that the atmospheric correction will improve the fidelity of the operational Landsat data.

7.4.4 Supporting I&T Data:

In addition to the same I&T data as used for the ALI atmospheric correction, the filter functions for the Landsat channels will be required.

7.4.5 Rationale:

The validation rationale will be the same as for the ALI atmospheric correction.

8.0 SCHEDULE

The spectral, spatial and image quality characterization of the LAC instrument and its radiometric calibration will be carried out during the entire assembly period as components are obtained and the instrument is fabricated. The final pre-delivery testing and calibration will be carried out in the period from February to July, 1998. This excludes a one-week period in June when the unit will be undergoing flatsat tests. I&T system level tests will include boresight alignment with the ALI and full system level operation of the LAC with the ALI, GIS, WIS and other EO-1 subsystems to determine possible interferences. It is expected that these test will occur in the period from August, 1998 to March, 1999, however, the LAC team will participate in any testing up to launch.

In-flight validation shall start with the engineering validation tasks as soon as the system is available to take data, presumably soon after launch. Verification of operation and determination of relative LAC/ALI boresight alignment shall occur first, followed by cross-correlation flight track determination. The science validation shall begin after correct operation of the LAC and ALI has been verified. It is expected that the atmospheric correction algorithms will evolve during the life of the mission, however, initial results on selected scenes will be available within two months after LAC operation is verified and calibrated ALI data is available. Initial operational results will be available within 6 months after this. Initial LAC retrieval results on selected scenes will be available within two months of verification of correct LAC operation and an initial operational algorithm will be available within 6 months after this. The schedule for performing the atmospheric correction on Landsat data will depend upon the schedule for performing nearly simultaneous EO-1/ Landsat observations. Initial atmospheric correction results on selected Landsat scenes will be available within two months after simultaneous calibrated LAC/ Landsat data becomes available, assuming that the Landsat characterization data has been available for algorithm development.

9.0 REQUIRED PERSONPOWER

Pre-launch validation of LEISA/AC will include calibration at a subsystem and a system level after integration with the spacecraft. As a subsystem, the required tasks will include wavelength calibration, spectral band shape, image quality, and radiometric sensitivity. On the spacecraft LAC will be calibrated for boresight alignment with the ALI and will be operated simultaneously with other instruments and subsystems to check noise levels and coordinated operation sequences. The pre-launch phase will require skills for operating and adjusting the LAC and its associated GSE, and for data processing to produce the validation products. Required personpower is 2 personyears total during FY98 and FY99.

Post-launch validation will include self-checks by observing known ground and atmospheric conditions, and most importantly, coordinated observing with the ALI and Landsat. The coordinated operations will produce multispectral data sets and simultaneous LAC hyperspectral data of characterized scenes. The previously calibrated multispectral data will be corrected for atmospheric affects and compared to known parameters of the areas observed to validate the algorithms. The required post-launch skills will be for image processing and data management, for development and adjustment of atmospheric correction algorithms, and for comparison of results with the science requirements. Required personpower is 1.5 personyears for 1 year post-launch.

10.0 REQUIRED FACILITIES

Pre-launch validation will take place in the LAC subsystem test area in buildings 11 and/or 20. GSE consisting of a data and telemetry interface, large volume data storage devices and a fast computer will be needed during this phase. After integration with the spacecraft, an interface will be needed to port data from the on-board recorder or the spacecraft GSE to the LAC dedicated GSE for analysis. We will require access to the ALI validation data in order to cross-validate the two instruments. We will also require the spatial and spectral instrument functions of the ALI, WIS, GIS and Landsat for the correction algorithms.

Post-launch validation will be performed in the LEISA lab in building 2 using data accessed over the electronic network. We will require data from both the EO-1/ALI operations facility and the Landsat operations facility. We will coordinate our operations and data processing, as well as our data requests with EO-1 and Landsat operations personnel. The LAC dedicated GSE will be adapted for post-launch data storage, handling, and processing. It is expected that the LAC data will be archived along with the ALI, WIS and GIS data at a facility other than the building 2 LEISA lab. The LAC team will not be responsible for this archive, but, in coordination with the EO-1 Project will supply algorithms to the archive for analysis of LAC data as these algorithms are developed and validated.

11.0 SIGNATURES

IPDT Provider:

Project Scientist:

Project Manager:

GSFC Program Manager:

NMP Program Manager: